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Arterial traffic congestion analysis using Bluetooth Duration data

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Abstract

The aim of this study is to assess the potential use of Bluetooth data for traffic monitoring of arterial road networks. Bluetooth data provides the direct measurement of travel time between pairs of scanners, and intensive research has been reported on this topic. Bluetooth data includes “Duration” data, which represents the time spent by Bluetooth devices to pass through the detection range of Bluetooth scanners. If the scanners are located at signalised intersections, this Duration can be related to intersection performance, and hence represents valuable information for traffic monitoring. However the use of Duration has been ignored in previous analyses. In this study, the Duration data as well as travel time data is analysed to capture the traffic condition of a main arterial route in Brisbane. The data consists of one week of Bluetooth data provided by Brisbane City Council. As well, micro simulation analysis is conducted to further investigate the properties of Duration. The results reveal characteristics of Duration, and address future research needs to utilise this valuable data source.

1. Introduction

Arterial traffic monitoring is a challenging undertaking. This is because arterial traffic is controlled externally by signals, which makes it difficult to develop a model for travel time estimation. Additionally the available data sources for traffic monitoring have been limited to conventional stop line detectors and signal timing data. However, due to recent advances in information technology, portable devices with Bluetooth communication are becoming more common. The Bluetooth signals recorded at several locations give the direct measurement of travel time between these locations, and hence will be a valuable alternative data source for arterial traffic monitoring.

Intensive research on traffic monitoring using Bluetooth records has been reported over a few years. Analyses for freeways and arterials demonstrate that Bluetooth records are capable of capturing traffic conditions as accurately as other data sources such as GPS floating vehicle data (Haghani et al., 2010, pp. 60-68, Quayle et al., 2010, pp. 185-193, Wasson et al., 2008, pp. 20–23). Other research involves analysis of traffic conditions during adverse weather (Martchouk et al., 2010, pp. 185-185) and road works (Haseman et al., 2010, pp. 40-53), and confirms that Bluetooth records are useful for monitoring non-recurrent events. (Bullock et al., 2011). In addition to the travel time analysis, matching Bluetooth records at different locations provides data on individual drivers’ movements, which makes it possible to analyse route choice behaviour in arterial network (Bullock et al., 2011).

There are two shortcomings in the previous research. One is the limited discussion on data filtering. Bluetooth data includes records from other transportation modes such as pedestrians, bicycles and atypical vehicles such as couriers, which result in significant scattering in the data. However, data cleansing methods have not been well examined. Another limitation to previous research is the lack of the use of “Duration” records. Duration data represents the time available for Bluetooth devices to pass through the coverage area of Bluetooth scanners. If a scanner is installed at an intersection, the Duration can be related to the intersection performance, and hence will be a valuable indicator for intersection operation.

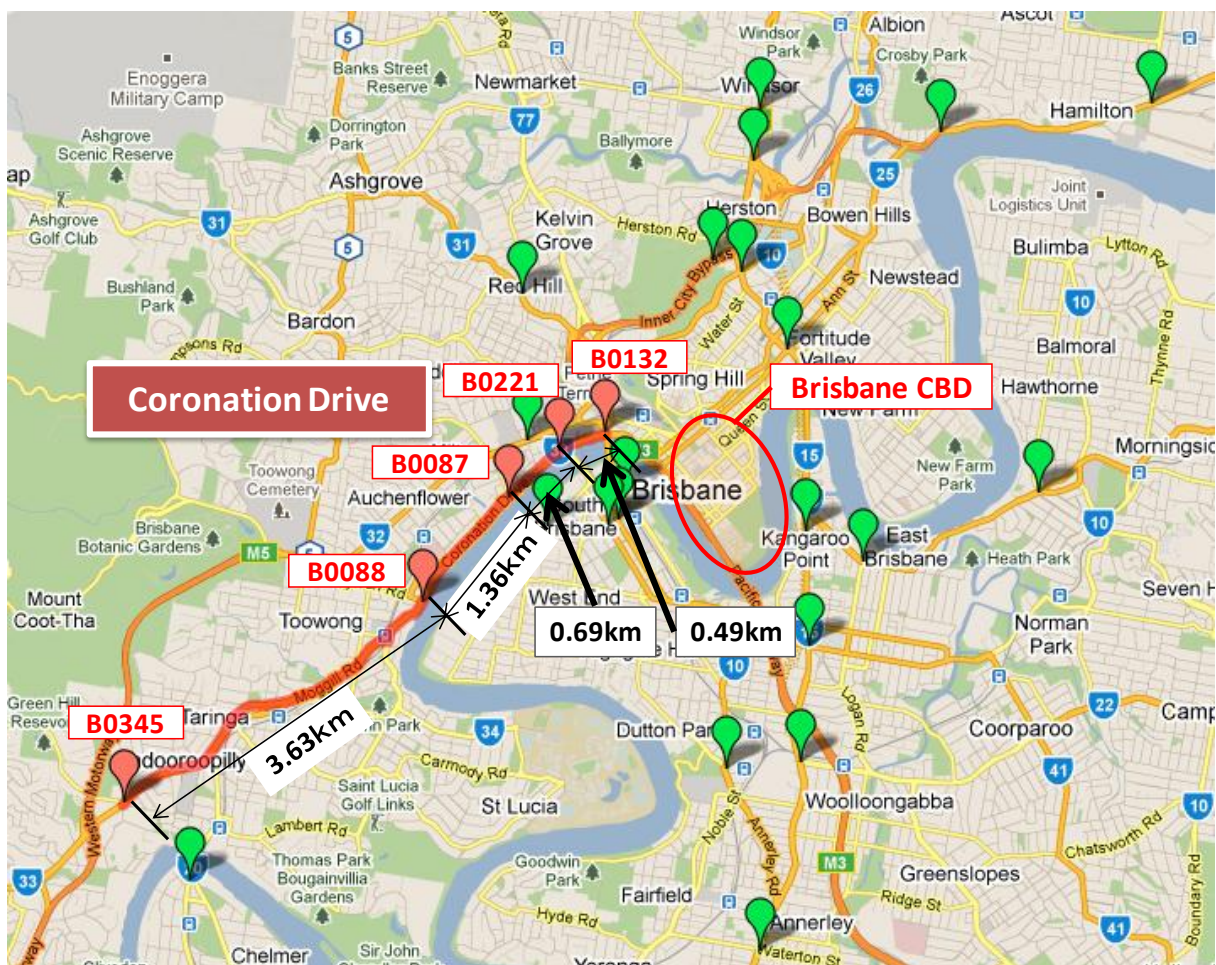
In this research, the Duration data as well as travel time data from Bluetooth records is used to capture the traffic condition of a main arterial route in Brisbane. The relationships between Duration and intersection performance is investigated, and future research needs are addressed based on the analyses.

2. Data and site description

Bluetooth scanners have been installed at 26 intersections in Brisbane city by Brisbane City Council for traffic monitoring purposes. For this research, one week of data was provided - from the 8th to the 15th of November, 2010. A Bluetooth scanner has a particular range of coverage area, within which the scanner detects any Bluetooth equipped devices such as mobile phones, laptops and other electronic devices, and records their Media Access Control (MAC) ID and Timestamp. MAC ID is a unique anonymous ID allocated to each device. If the same MAC ID is recorded at two successive two scanners, the difference of the upstream and downstream passing time gives the space-mean travel time between the two locations.

The study site is an approximately 6km section of inbound road on Coronation Drive. This route is the main signalised arterial connecting Brisbane's western suburbs with the CBD, and hence is heavily used by commuters. There are 5 Bluetooth scanners (B0345, B0088, B0087, B0221 and B0132) along the route as represented in Figure 1. The green bubbles represent the other scanners' locations which are not used in this research.

Figure 1: Bluetooth scanner locations and study route



3. Travel time of signalised arterial using Bluetooth data

3.1 Definition of travel time

Bluetooth scanner detects active Bluetooth devices within its coverage area. The obtained travel time is a zone-to-zone travel time, rather than a point-to-point travel time such that obtained by Automatic Vehicle Identification (AVI) data.

In this study the Bluetooth data has the following three fields:

- ID: a unique encrypted number for MAC ID of the Bluetooth device detected
- Timestamp: time when the scanner first records the Bluetooth device
- Duration: time taken for the Bluetooth device to pass through the scanners' coverage area

If the road section between two successive scanners is defined as a link, simple subtraction of upstream and downstream timestamps gives link travel time, which includes Duration at the upstream intersection. However, it can also include the delays both at upstream and downstream intersections. Moreover, in an urban signalised street, link traffic conditions or travel time are controlled by the downstream intersection, rather than the upstream one. Therefore it is more appropriate that travel time is related to the downstream intersection traffic condition. In this research, link travel time is defined as the time difference of the "exit time" from the coverage area, where exit time is defined as the summation of timestamp and Duration (Figure 2).

$$t_{v,i} = T_{v,i} + D_{v,i}$$

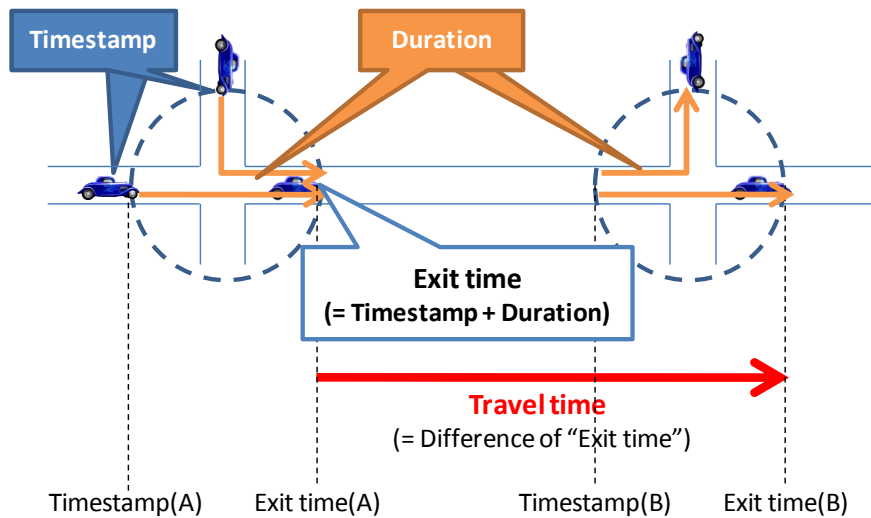
where t , $T_{v,i}$ and $D_{v,i}$ are the exit time, timestamp and duration of a Bluetooth device with ID v at Bluetooth scanner i , respectively

$$tt_v = t_{v,i} - t_{v,j}$$

where tt_v is the travel time for a Bluetooth device v from scanner j to i .

In other words, link travel time is the time difference between the last detection at the upstream and last detection at the downstream.

Figure 2: Link travel time calculation



3.2 Matching process and sample size

To obtain travel time, an ID is matched between detectors along the street. In arterial streets, the records come from various kinds of transportation modes, such as pedestrians, bicycles and atypical vehicles such as couriers or busses, and overly long travel time can be observed. Additionally, travel time can be influenced by different turning movements at intersections. In order to reduce these effects, two filters are applied for extreme records:

- a) Unrealistic travel time filter: records which take more than 30 minutes between two successive detectors are considered unrealistic for vehicle travel time and are therefore removed
- b) Through movement filter: records which pass more than three successive scanners are considered in the travel time calculation

In addition to these filters, another filter is also employed as introduced in the next Section.

Table 1 shows the number of samples along the study route depending on the number of successive scanners where the same ID is recorded. For instance, the number of samples which passed all B0345, B0088 and B0087 is 6,960. Among them, samples which passed more than three scanners are thought to go straight through the scanners in the middle. For instance, the sample which passed all B0345, B0088 and B0087 are supposed to have gone through the scanner of B0088. Therefore the travel time from B0345 to B0088 of these samples does not include the effect of turning movements. As such, for link travel time calculation, IDs are matched not just between two scanners, but also with one scanner ahead of the direction.

3.3 Arterial link travel time using Bluetooth record

After removing the extreme records, a simple filter is applied to remove scattering plots. 75 percentile of link travel time is calculated for every 5 minutes, and data with more than 75 percentile value is removed. Figure 3 shows the travel time of three links for the whole data period. During weekdays, morning peak is observed around 7am, and another peak occurs in the evening. However, there is no peak period on weekends on the route, because this route is most heavily used by commuters mainly on weekday mornings.

Another remarkable point to note in Figure 3 is that two different levels of travel time, bi-modal travel time, are observed in link B0087-B0221 during off-peak periods; one is about 1min and the other is about 2min. This link is the shortest of the three, and there is only one signalised intersection in the middle of the link. As the research is focused only on through movements, this bi-modal travel time can be related to the delay at the mid-link signal; that is, the lower travel time occur when the signal is green and the upper travel time when it is red. Therefore, these figures show that Bluetooth data captures signalised arterial characteristics.

Table 1: Number of samples (from 8th to 15th of Nov, 2010)

Pair of Scanners	Number of Samples (Total for whole period)
B0345->B0088	8,463
B0345->B0088->B0087	6,960
B0345->B0088->B0087->B0221	6,209
B0345->B0088->B0087->B0221->B0132	1,630
B0088->B0087	39,054
B0088-> B0087->B0221	33,998
B0088->B0087->B0221->B0132	5,970
B0087->B0221	68,111
B0087->B0221->B0132	11,271
B0221->B0132	15,680

4. Intersection performance analysis using Duration data

4.1 Travel time and Duration

Bluetooth Duration refers to the time between the first detection by a scanner until the time the Bluetooth device falls outside the scanner's coverage area. If the scanner is installed at an intersection, the Duration is equivalent to the time occupancy around the intersection, and this will indicate the intersection performance.

To begin with, we investigate the relationship between link travel time and Duration, since, as discussed in Section 3.1, link travel time is controlled by the downstream intersection, assuming that there is no major mid-link source of delay such as mid-link intersections. Figure 4 -Figure 6 show the plots of link travel times and Duration of the research data set using the travel time obtained in Section 3.3. Samples with unrealistic Duration value such as 1 second are considered as noise data and removed. There are two distinctive patterns found in these figures. One is that the minimum Duration gathers around 20 seconds regardless of the travel time. This indicates that these samples are running at around 36km/h, which is nearly free flow speed in signalised arterials, because the scanner's coverage area is approximately 100m radius (Brisbane City Council, 2010).

The second pattern indicates that, apart from the plots of minimum Duration, Duration increases as travel time increases, especially in the plot of B0221, although the relationship is weak in B0088 and B0087. This implies that the link travel time of B0087-B0221 is mostly affected by the downstream intersection. On the other hand, in link B0345-B0088 and B0088-B0087, other factors such as mid-link delays are dominant causes of the traffic congestion.

Although the relationships between travel time and Duration can be observed, the characteristics are not clear because of the impact of factors such as road environment and noises in the data. In order to determine the potential of Duration data, sensitivity analyses are conducted. A simple network where there is only one signalised intersection is analysed using a micro simulation model. Simulation provides a controlled environment necessary to explore the potential benefits of the duration data.

Figure 3: Travel time for whole study period

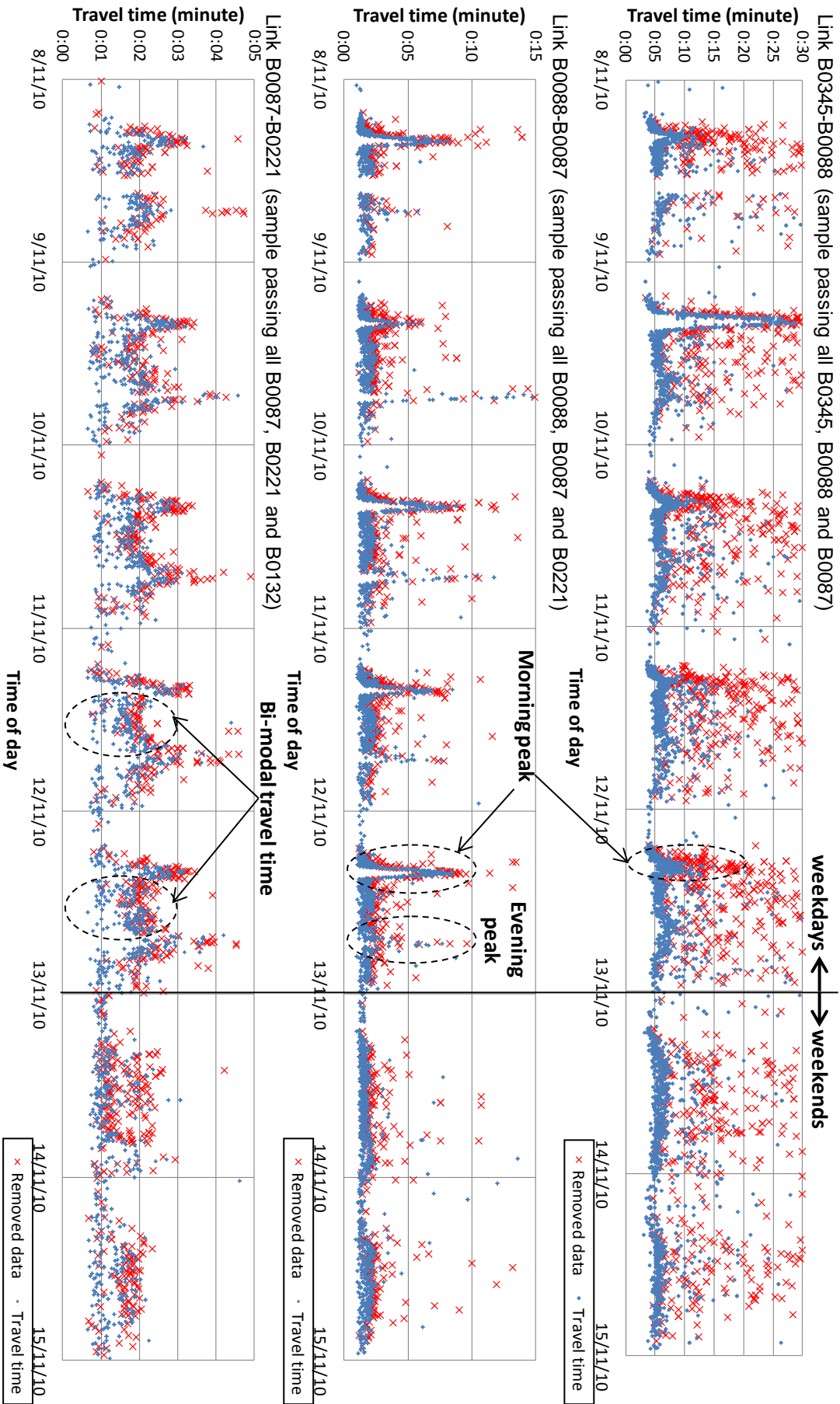


Figure 4: Travel time and Duration from real data (Link B0345-B0088)

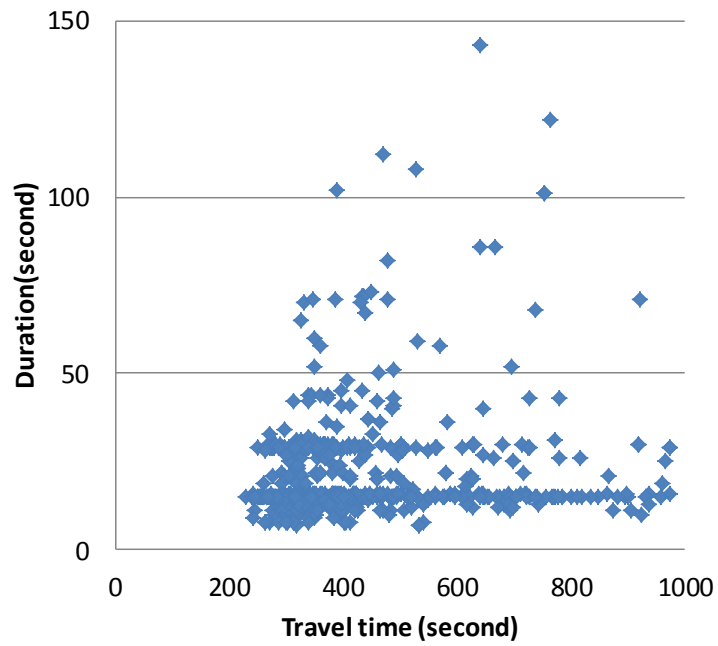


Figure 5: Travel time and Duration from real data (Link B0088-B0087)

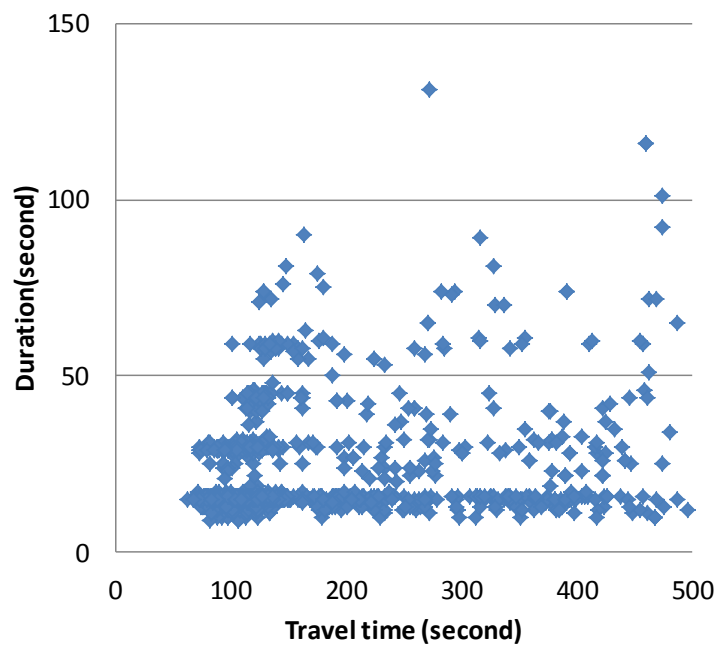
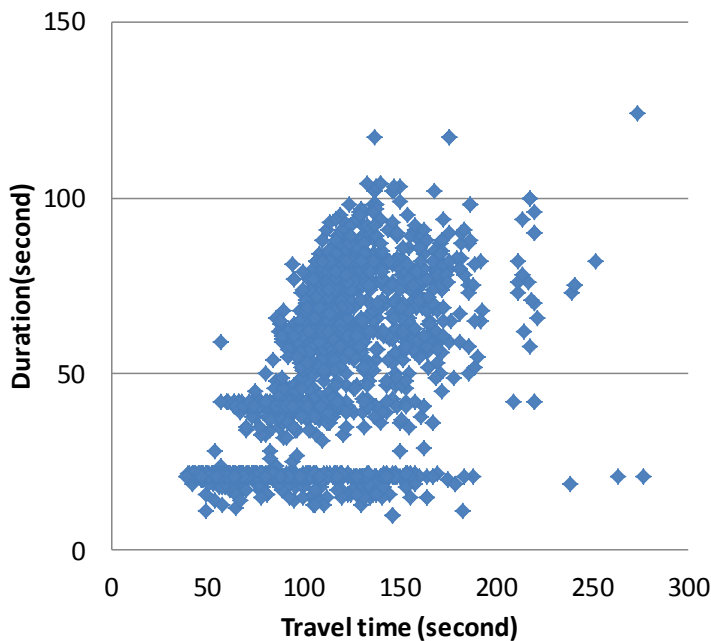


Figure 6: Travel time and Duration from real data (Link B0087-B0221)



4.2 Sensitivity study of Duration

4.2.1 Sensitivity to the coverage area

The Bluetooth scanner coverage areas vary depending on the surrounding environment and the signals from other devices equipped with active Bluetooth. Duration does not always provide a vehicles' dwelling time within a fixed zone; rather, it varies randomly. This research investigate – through the use of AIMSUN microscopic simulation (Transport Simulation Systems)- how Duration changes, depending on the coverage area.

Figure 7 illustrates the test network. The network is a single lane with signal cycle of 120 seconds, and a green split of 0.5. The simulation is performed for both under-saturated and over-saturated traffic conditions. There are seven detectors in the network: an upstream detector and three pairs of detectors imitating different coverage areas, located at 50m, 100m and 150m upstream and downstream from the intersection. Link travel time and Duration are calculated for each coverage area. The example - when coverage area is 100m - is presented in Figure 7.

Figure 8 shows the relationships between travel time and Duration for different aforementioned coverage areas (*diamond*, *square* and *triangle* points corresponds to 50m, 100m and 150m of coverage area, respectively).. There are scatters observed in Duration value for different coverage areas. Additionally four domains can be identified in the graph. Each regime is connected to traffic conditions, as follows:

- Group1: This group is the sample which does not experience any stops or delays in the whole link. Consequently all the samples are plotted at the point of (free flow travel time, free flow Duration).
- Group2: These vehicles experience delays in the middle of the link, but they do not stop in the scanner's coverage area. Therefore, as illustrated in Figure 8, they are plotted at the minimum Duration area regardless of the link travel time.
- Group3: This group of vehicles stops at the red signal time period, and the Duration jumps up to a certain value which is equal to the red time. As the queue disappears,

both link travel time and Duration decreases linearly, which forms the straight line as shown in Figure 8. While the line forms, vehicles experience the delay only in the coverage area. Therefore the slope of the line is always 1.

- Group4: In Figure 8, some plots are found for the coverage area of 150m. These samples stop twice in the scanner's coverage area, and therefore, the maximum Duration is equivalent to the double of red time.

For better understanding, a self explanatory diagram indicating different groups of vehicles are illustrated with the help of a time space diagram in Figure 9, where *black*, *dotted* and *gray* lines represents Groups 1, 2 and 3, respectively.

These results suggest there are two factors causing the scatters in the plot of travel time and Duration. First, Duration value jumps up to the maximum, which is equivalent to the signal red time period. In the simulation, fixed signal timing was employed, whereas in reality, signal timing changes, depending on the time of the day or real-time traffic conditions. Therefore, the plot scatters more significantly in the vertical direction.

Another factor is that the vertical range of scatters depends on the number of stops in the scanner's coverage, and the variation in the coverage area can induce a wider range of Duration. In this simulation, some vehicles stopped twice in 150m to the stop line, which causes another level of Duration.

Figure 7: Test network

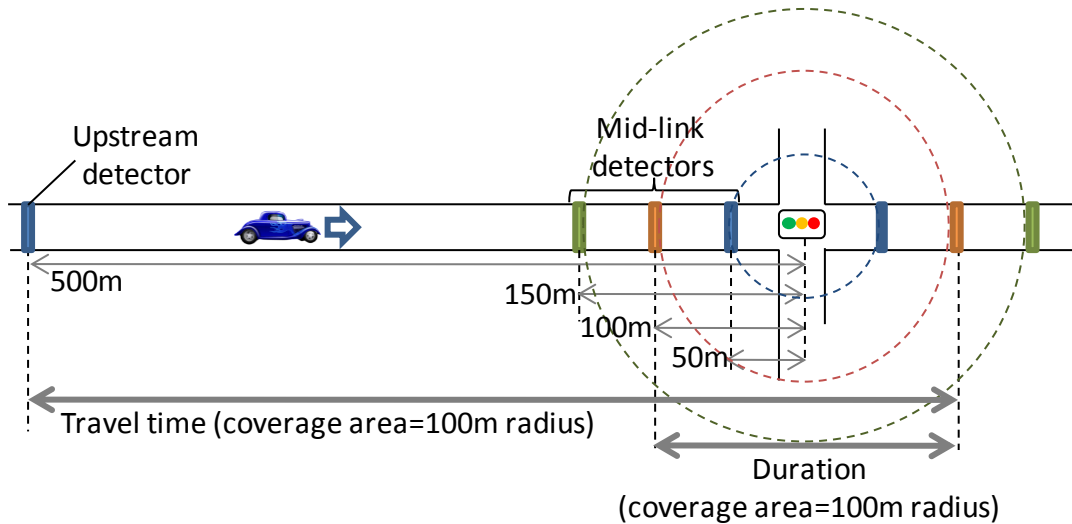


Figure 8: Travel time and Duration for different coverage areas

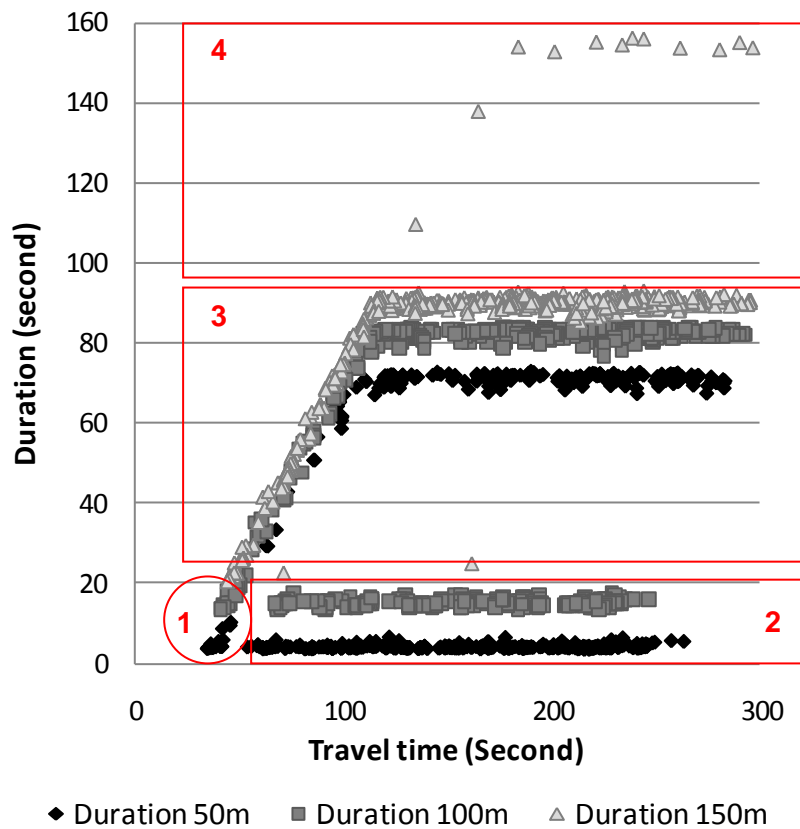
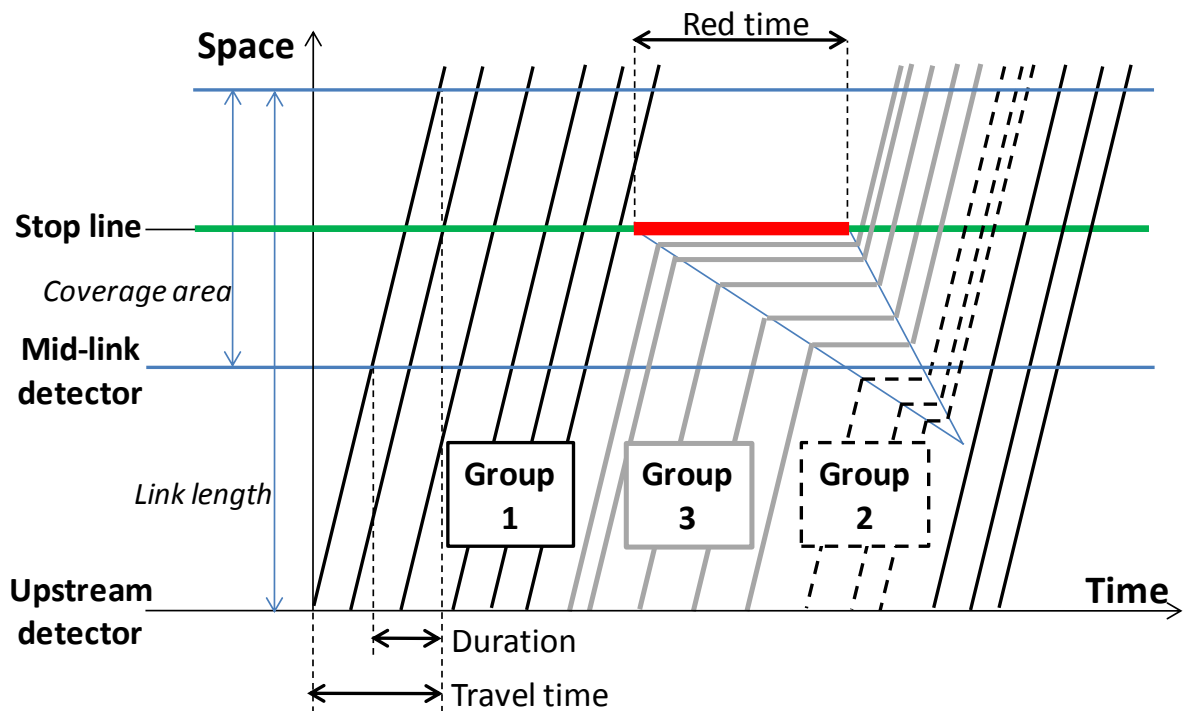


Figure 9: Travel time and Duration for different coverage areas



4.2.2 Sensitivity to the degree of saturation

The initial objective of this research is to examine the benefits of Duration data for intersection performance indication. Now, we investigate how link travel time and Duration change depending on the congestion level. To assess this, the degree of saturation at an intersection, to represent the level of congestion is investigated. The degree of saturation stands for the ratio of demand to capacity at an intersection for a lane group.

$$\text{Degree of saturation} = v/c$$

where v and c are demand and capacity at an intersection for a lane group, respectively. If an intersection keeps under-saturated, the degree of saturation ranges from 0 when the demand is zero to 1.0 when the demand is equal to the capacity. The value above 1.0 indicates an over-saturated condition (Transportation Research Board, 2000).

The simulation network is the same as described in Sub-section 4.2.1. Signal timing is fixed so that the green-cycle ratio is 0.5 allowing an intersection capacity of 900veh/h. A series of demands is set according to the degree of saturation from 0.50 to 1.20 in 0.1 intervals. The scanner's coverage area is restricted to a 100m range.

Figure 10 summarises the results. When the degree of saturation is low (Figure 10(a)), the relationship between travel time and Duration is linear. This suggests that queues form at the red time, but quickly disappears during the green time, and hence the intersection performs well. However, as the degree of saturation becomes critical (Figure 10(b)), the lower and upper lines of Duration start building regardless of the travel time. This is because queues form beyond the scanner's coverage area and some vehicles experience stops or delays in the middle of the link. Finally, once the degree of saturation is over 1.00 (Figure 10(c)), more plots are found along the minimum and maximum Duration value. This suggests that the intersection performance is so diminished that the link travel time becomes longer while Duration retains the same level, since no vehicle stops within the coverage area more than twice.

In summary, as the degree of saturation increases, that is, as the queue builds up beyond the coverage area, the plot stretches horizontally. This suggests that the scatter in a horizontal direction represents the delay caused outside of the scanner's coverage area. Moreover, if there is no major mid-link source of delay such as signalised intersections, relationships between link travel time and Duration will be the function of the downstream intersection condition. Figure 10(d) illustrates this idea. Once the threshold line is determined, the plots can be categorised into under-saturated and over-saturated conditions, which can be used to estimate intersection performance.

4.3 Discussion on the characteristics of Duration

The sensitivity analyses revealed the causes of scatters of travel time and Duration observed in Figure 4 -Figure 6 as follows:

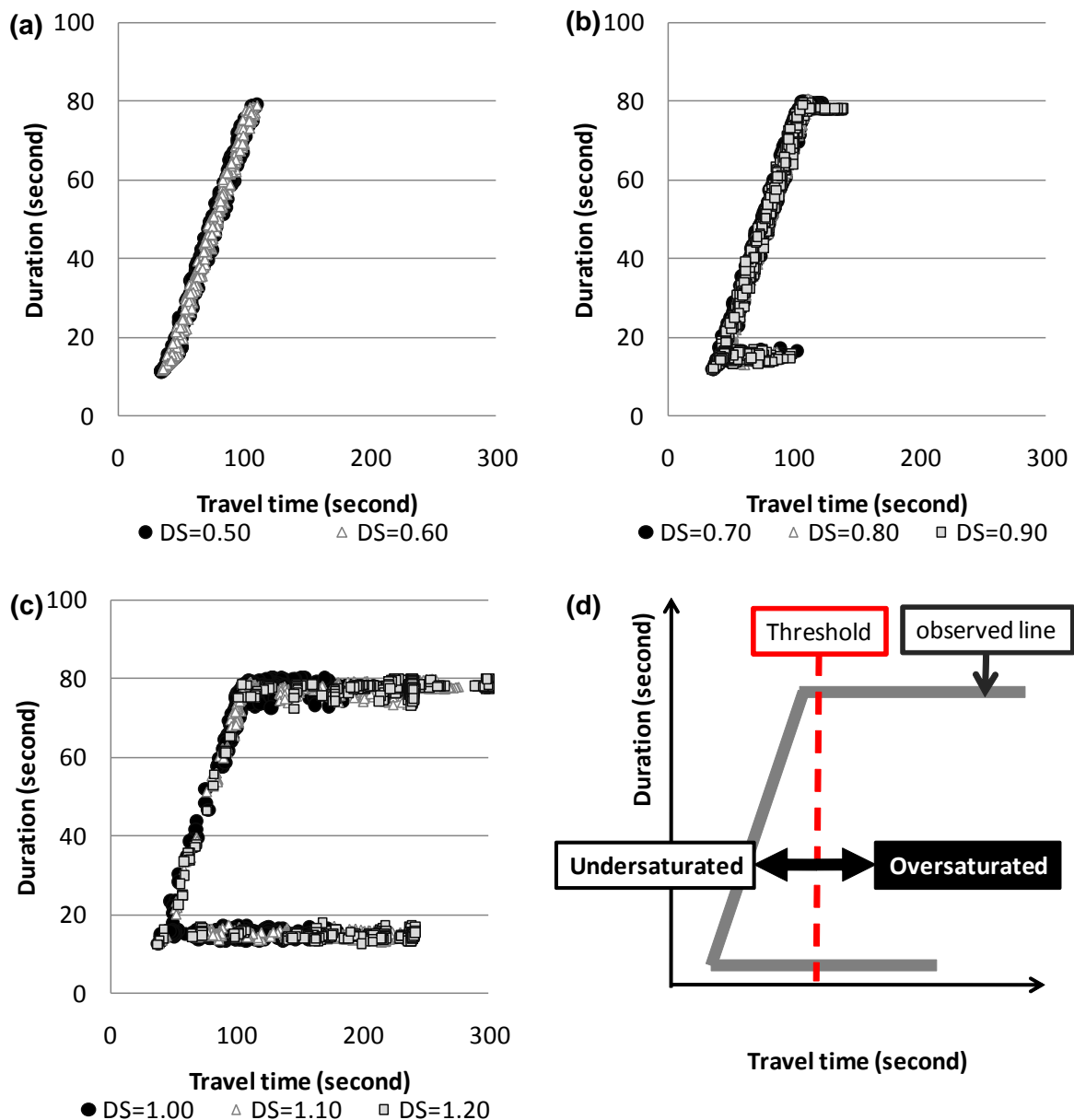
- a) Fluctuation in scanner's coverage area
- b) Variation in signal timing
- c) Mid-link delays

In the sensitivity analyses, there are only three different scanner coverage areas. However, in reality, the coverage area changes randomly within the maximum coverage area, which results in significant noises in the Duration. Further, this research has revealed the relationships between Duration and red time at an intersection. In this simulation, the signal timing was fixed. However, it changes depending on the time of day or real-time traffic condition, and causes variation in Duration values. Therefore the data set should be categorised according to these variables. Finally, the scatters in horizontal direction indicate the amount of mid-link delays. The more mid-link signalised intersections that exist, or the longer delays vehicles experience, the more widely the plots spread. Moreover, assuming

that there is no cause of delay in the middle of the link, the horizontal scatter can be related to the downstream intersection performance. In order to fully utilise the Duration data, these relationships should be further investigated for longer periods using other data sources such as signal timings.

In addition to these factors, there still remain the effects of different transportation modes such as bicycles and pedestrians, which results in longer travel time. Although three filters have been applied, they do not fully consider the characteristics of various modes. Further development of the filter, taking into account the difference between modes, is essential.

Figure 10: Travel time and Duration for different degree of saturation (coverage area = 100m)



5. Conclusion

This research analysed the travel time of a signalised arterial route in Brisbane using Bluetooth data, and examined the potential use of Duration data, which has been largely ignored in previous research. The research confirmed that travel time obtained from Bluetooth records captured traffic characteristics in urban arterial streets, such as morning and evening peaks during weekdays, and bi-modal travel time in a particular link, for instance. The sensitivity analyses on the relationship between travel time and Duration revealed some remarkable characteristics. The research revealed that the vertical scatter of the plots is mainly caused by the fluctuation of the scanner's coverage area and the change in the signal timing, and the horizontal scatter represents the degree of saturation at an intersection as well as the delay in the middle of the link. Although this research figured out some basic properties of the Duration data, future research is needed in order to fully exploit the valuable data source. For instance, there still remain the effects of different transportation modes such as bicycles and pedestrians, which results in longer travel time. Although three filters have been applied, they do not fully consider the characteristics of various modes. Moreover, Bluetooth samples can be biased by more than one active device with a traveller or a group of travellers with active devices sharing the same mode such as a bus. This bias can lead to over representation of vehicles with Bluetooth devices. In order to overcome these problems, further development of the filter, taking into account the difference between modes, is essential. Lastly, further investigation on the Bluetooth scanners' coverage area is needed for more reliable estimation of travel time and Duration.

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